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East Asian seas: A hot spot of pelagic microplastics

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ABSTRACT

To investigate concentrations of pelagic micro- (<5 mm in size) and mesoplastics (>5 mm) in the East Asian seas around Japan, field surveys using two vessels were conducted concurrently in summer 2014. The total particle count (pieces km^{-2}) was computed based on observed concentrations (pieces m^{-3}) of small plastic fragments (both micro- and mesoplastics) collected using neuston nets. The total particle count of microplastics within the study area was 1,720,000 pieces km^{-2}, 16 times greater than in the North Pacific and 27 times greater than in the world oceans. The proportion of mesoplastics increased upstream of the northeastward ocean currents, such that the small plastic fragments collected in the present surveys were considered to have originated in the Yellow Sea and East China Sea southwest of the study area.

1. Introduction

According to a recent estimate by Jambeck et al. (2015), the volume of plastic waste input from the East Asian continent into the surrounding ocean is the largest in the world. Marine plastic debris can be found widely on the beaches of East Asian countries (e.g., Kusui and Noda, 2003; Kako et al., 2010; Nakashima et al., 2011; Zhou et al., 2011; Hong et al., 2014; Kuo and Huang, 2014). In the environment, plastic debris gradually degrades into mesoplastics (>5 mm) and thereafter into microplastics (<5 mm) because of exposure to ultraviolet radiation and mechanical erosion on beaches (Andrady, 2011). Hence, dense concentrations of pelagic microplastics are liable to be observed in the East Asian seas in comparison with other oceans. However, except for a few previous studies conducted within limited spatial scope (Isobe et al., 2014; Zhao et al., 2014), there are no estimates regarding the concentrations of microplastics over wide areas of the East Asian seas. In the present study, the concentrations of microplastics in the seas around Japan were surveyed concurrently using two training vessels during summer 2014. The primary objective of the present study was a comparison of the concentrations of microplastics in the East Asian seas around Japan with those observed in the world oceans (Cózar et al., 2014; Eriksen et al., 2014). A question of particular interest is whether the East Asian seas are regarded as a "hot spot" of microplastics.

The secondary subject of interest concerns the source(s) of meso- (>5 mm) and microplastics (<5 mm) found within the study area. Hereinafter, the term "small plastic fragments" is used to represent both meso- and microplastics. The transport process of small plastic fragments is a challenging topic in physical oceanography, because pelagic plastic fragments are mostly made of polystyrene and polyethylene: 98.5% in Reisser et al. (2013) and 78% in Isobe et al. (2014). The plastic fragments are less dense than seawater and they move within the upper 1-m "skin" layer of the water (Reisser et al., 2015) where highly turbulent motion (Kukulka et al., 2012) and Stokes drift (Isobe et al., 2014) make their behavior complex. Nonetheless, the ratio of the quantity of mesoplastics within the small plastic fragments is likely to increase nearer to the contamination source, because macroplastic debris gradually degrades into smaller fragments as it moves within the oceans. Thus, it is anticipated that the size distribution of the plastic fragments and their spatial distribution could be used as strong indicators of their sources.

2. Methods

2.1. Study area

Japan is generally surrounded by northeastward or eastward ocean currents. On the surface current map (Fig. 1), the eastward or northeastward Kuroshio Current, with a speed of around 1 m s^{-1} (~2 knots), can be seen south of Japan. It is well known that the Kuroshio Current separates from Japan at 35°N and then flows eastward as the Kuroshio Extension (e.g., Stommel and Yoshida, 1972). In the Sea of Japan, the northeastward Tsushima Current is connected continuously to the northeastward ocean currents over the East China Sea shelf (Isobe, 2008). The Tsushima Current separates into at least two branches in the Sea of Japan: one is the offshore branch ($O(10)$ cm s^{-1}) that flows eastward in the central portion of

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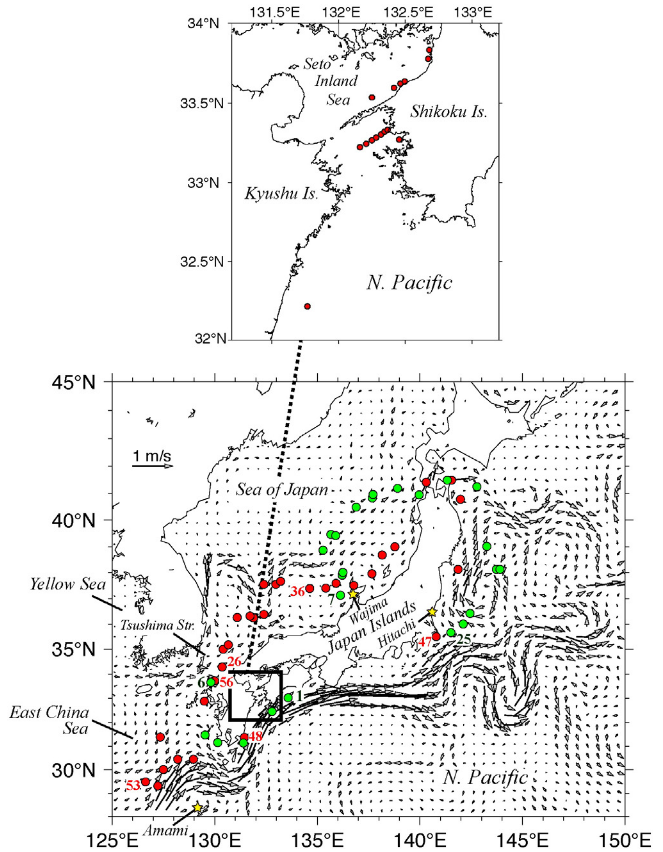

Fig. 1. Study area of the present surveys (lower panel) and the Seto Inland Sea in Isobe et al. (2014) (upper panel; 15 stations shown by the red spots). In the lower panel, the samplings at stations shown by green (red) spots were conducted by the *T/V* Umitaka-Maru (Shinyo-Maru). The station numbers are shown at selected stations. The yellow stars indicate locations of the three NOWPHAS wave observatories. The vectors represent surface ocean currents reproduced in the Data Assimilation Research of the East Asian Marine System (DREAMS; Hirose et al., 2013). The velocities were averaged over the period July through August 2014 (survey period in Table 1).

the sea, while the other is the nearshore branch ($O(10)$ cm s^{-1}) that flows northeastward paralleling Japan (Kawabe, 1982).

2.2. Field surveys

The dual surveys were conducted concurrently during the period of July 17 through September 2, 2014, using two training vessels: the *T/V* Umitaka-Maru (1886 tons) and *T/V* Shinyo-Maru (649 tons), both belonging to the Tokyo University of Marine Science and Technology. To collect the small plastic fragments, 56 stations were placed around Japan, except for an area to south of the country (lower panel of Fig. 1). The surveys were conducted in a clockwise direction from Sta. 1 to Sta. 25 by the Umitaka-Maru and from Sta. 26 to Sta. 56 by the Shinyo-Maru (see Table 1 for detailed schedule). The sampling of the small plastic fragments was conducted three times daily (0600, 1300, and 1800 LST), although some samplings were skipped or delayed because of uncontrollable circumstances such as stormy weather.

Table 1
Stations and survey periods in 2014.

Vessels	Stations	Date
Umitaka-Maru	Sta. 1–Sta. 25	July 17–August 8
Shinyo-Maru	Sta. 26–Sta. 47	July 20–August 4
Shinyo-Maru	Sta. 48–Sta. 56	August 21–September 2

A neuston net (5552; RIGO Co., Ltd., Tokyo, Japan), originally designed for sampling zooplankton, fish larvae, and fish eggs near the sea surface, was used for sampling the small plastic fragments. The mouth, length, and mesh size of the net were 75 × 75 cm, 3 m, and 0.35 mm, respectively. The lower limit of the microplastics discussed in the present study was dependent on this mesh size. The training vessels towed the neuston nets around each station continuously for 20 min at a constant speed of 2–3 knots. A flow meter (5571A; RIGO Co., Ltd.) was installed at the net mouths to measure the water volume passing through during the sampling; otherwise, the estimates of the concentration of small plastic fragments would become inaccurate because the speed of the ocean current within the study area frequently exceeded $O(1)$ knot. Once the surveys were completed, the flowmeter readings and net mouth dimensions (75 × 75 cm) were used to estimate the volume of water filtered during each tow.

In addition to comparisons with previous surveys in other oceans (e.g., Cózar et al., 2014; Eriksen et al., 2014), the results of the present surveys were compared with the findings of work conducted in the Japanese coastal area by Isobe et al. (2014). Their field surveys were conducted at 15 stations in the western Seto Inland Sea during the summers from 2010 to 2012 (upper panel of Fig. 1).

2.3. Measurements of small plastic fragments

The small plastic fragments collected were brought back to the laboratory to distinguish them from other suspended matter. All samples were first observed on a monitor display via a USB camera (HDCE-20C; AS ONE Corporation, Osaka, Japan) attached to a stereoscopic microscope (SZX7; Olympus Corporation, Tokyo, Japan) and identified visually by their color and shape (Hidalgo-Ruz et al., 2012). Polymer types of material were identified using a Fourier transform infrared spectrophotometer (FT-IR alpha; Bruker Optics K.K., Tokyo, Japan) when fragments were too small for visual differentiation between microplastics and biological matter. Lines (probably fishing lines), expanded-polystyrene particles, and biological elements were removed before any further analyses. Primary microplastics such as pellets (Cole et al., 2011) were included in the subsequent analyses despite their small numbers.

The numbers of remaining pieces (hereinafter "quantity") in each size range were counted with an increment of 0.1 mm for microplastics, 1 mm for mesoplastics between 5 and 10 mm, and 10 mm for mesoplastics >10 mm. The sizes were defined by the longest length of each irregularly shaped fragment visible on the monitor display, as measured using image-processing software (ImageJ downloaded from http://imagej.nih.gov). The quantities within each size range were thereafter divided by the water volumes measured by the flow meter at each sampling station to convert them to quantities per unit seawater volume (hereinafter "concentration" with units of pieces m^{-3}). The concentration of microplastics (mesoplastics) was computed by integrating the concentrations of the fragments with sizes from 0.3 to 5 mm (from 5 to 40 mm).

The data sets produced in this study are available at figshare (Isobe et al., 2015).

2.4. Data analyses

To compare the estimated concentrations of microplastics obtained in this study with previous studies that deduced quantities per unit area (e.g., Eriksen et al., 2014; referred to as "count density" or "total particle count" in their paper), the concentration (pieces m^{-3}) of microplastics was integrated vertically (pieces km^{-2}). The quantities of small plastic fragments decrease exponentially into deeper layers (Kukulka et al., 2012; Reisser et al., 2015), and thus, the vertical distribution of the concentration (N) of microplastics can be expressed as